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## Barge's study under impact loads

**M Nechita and C I Mocanu**

Dunarea de Jos University of Galati, Naval Architecture Faculty,  
Department of Naval Architecture, Galati, 111 Domneasca Street,  
800201, RO

E-mail: manuela.nechita@ugal.ro

**Abstract.** The aim of this paper is to present a method of increasing the safety of inner water navigation. It concern on improving the structural resistance of a barge during design process. Numerical structural analyses of the deck and the board are purposed to solve the problem. Different values of friction coefficient steel on steel are considered as input data. Naval structure's behaviour is analysed using the area and the volume values of the struck surfaces. The post-processing of data shows an influence of the friction coefficient on Von Mises stress of the deck's structural components. This method also allows evaluation of the barge damages.

### 1. Introduction

The Waterborne sector in Europe is an important field that meet the UN Sustainable Development goals and the COP21 objectives. Transport in EU is increasing and inland waterways, such as Rin – Mein – Danube, could be a solution in terms of CO2 emissions reduction [1]. Development of this VII pan European transport corridor requires the safety of the vessel traffic that is the most important aspect of the transport of goods by water [2]. The barges are often used for the transport of the heavy goods on waterways and for technical marine interventions, being recommended as intermodal connections [3]. Due its flat bottom the barge sails on Danube river as long as the fair's depth remains over 2.8 meters, as mentioned in the programme for trans-border cooperation Romania-Bulgaria 2007-2013.

Designing barges is done in accordance with the rules of classification societies, as DNV-GL. The maximum dimensions of the barges that navigate the Danube are: 88 m long, 12 m wide, 3.3 m draft and 3 000 T load capacity. The barge behaviour on different loads, static / dynamic or local/global, is studied in naval architecture field. Danube river navigation or coastal route conditions are also included in researches about barges [4].

Our paper dials with a local numerical analysis of a barge under impact loads, in order to study its structural resistance at the interaction with the environment. The dynamic impact process is described by a non-linear explicit transient analysis. Nastran NX Femap 11.4.2 FE software is used for simulation, analysis and pre-post processing. The influence of friction and the geometric design data are studied. Conclusions of our paper show that the friction generates the increasing of Von Mises stresses with decreasing the curvature of the barge's frames. Our future work dials with the influence of the barge's frames curvature on Von Mises stress under impact loads, considering also the experimental conclusions from Balan et al [5] and Popescu and Nechita [6] studies.



## 2. Barge's model CAD Design

It was realised the 3D model of B2000 tdw barge's bow geometry using the project data from technical documentation designed by ICEPRONAV Galati. It includes the area between the watertight bulkhead from frame 120 and the chain tube bulkhead that start at frame 126. The general data [7] are mentioned in table 1.

**Table 1.** The B2000T barge's ggeneral data.

General data	Symbol	Design data
Length over all	L <sub>OA</sub>	76.18 m
Length between perpendiculars	L <sub>PP</sub>	75.72 m
Breadth	B	11.00 m
Depth	D	3.60 m
Draft	T	3.02 m
Intercostal distance		0.50 m
Water line distance		0.50 m
Displacement	$\Delta$	338 t
Deadweight	TDW	2000 t

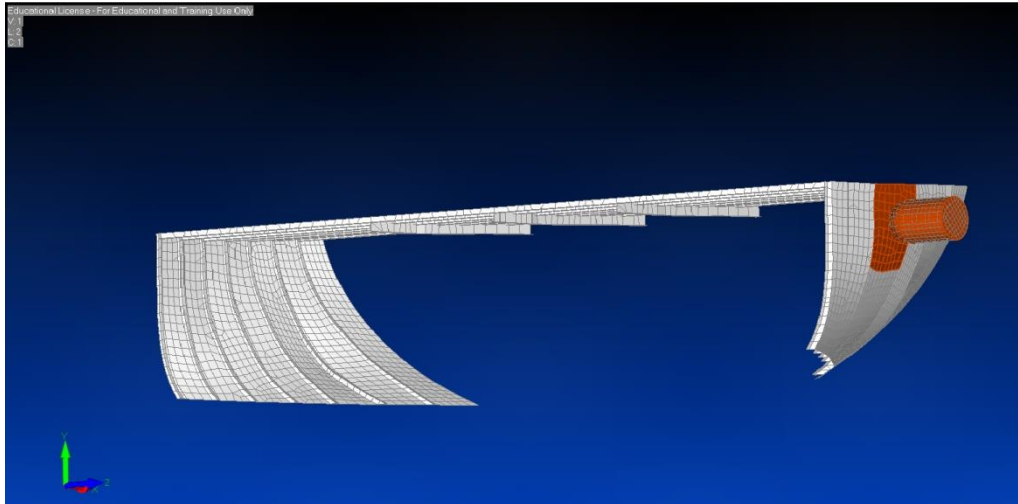
The deck is stiffened with 7 elements in transversal direction and 3 elements in longitudinal one and the side is stiffened with 7 side stiffeners. Table 2 contains the barge's CAD model design data, used in modelling it with Nastran NX Femap 11.4.2.

**Table 2.** The barge's CAD model design data.

Structure elements	Dimensions (mm)
Shell deck thickness	8
Shell board thickness	6
Deck transversal stiffeners	L 80 x 65 x 10
Deck longitudinal stiffeners	T 200 x 80 x 6
Board stiffeners	L 80 x 65 x 6
Intercostal distance	500
Distance between longitudinals	1994 to stern and 1850 to bow

## 3. Barge's model FE analysis

In order to increase the safety of the barge traffic, was checked its structural resistance at a collision with an energy  $E=1\text{ kJ}$ , realized by impacted its starboard shell, on perpendicular direction, by a body that have velocity  $v=1\text{ m/s}$  and mass,  $m=2\text{ tones}$ , as shown in figure 1. Three collision scenarios are analysed, the barge being impacted into its three frames with different curvature. Impact is a complex phenomenon and plastic- nonlinear material is used for both barge and the impactor, taking into account the coefficient friction between them.



**Figure 1.** The barge's structure impacted on starboard shell at 123 frame ( $x= 65.62$  m,  $y= 3.19$  m,  $z= 5.44$  m).

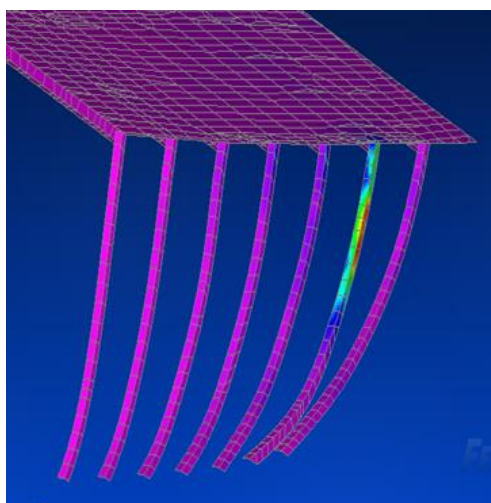
The material properties are recorded in table 3.

**Table 3.** The plastic-nonlinear material properties.

Property	U.M.	Value
Young Modulus, E	MPa	$2.1 \times 10^5$
Poisson coefficient	-	0.3
Density	tone/mm <sup>3</sup>	$7.85 \times 10^{-9}$
Yield stress	MPa	236.2
Ultimate limit stress	MPa	432.6

### 3.1. Impact FE analysis on initial barge's structure

The stress diagrams shows that collisions generate local loads, around the impact point, of the starboard shell and on the stiffeners, as we can see in figure 2.



**Figure 2.** The variations of Von Mises stress at 125 frame ( $x= 66.62$  m,  $y= 3.19$  m,  $z= 5.29$  m) impacted with  $E = 1$  kJ ( $v=1$  m/s),  $\mu = 0.6$ .

**Table 4.** The influence of the friction coefficient on FE analysis's output values resulting from the impact on the barge's structure with E= 1kJ (v=1m/s) at frame 121 (x=64.62 m, y= 3.19 m, z= 5.49 m).

Structure elements	Friction coefficient $\mu$	Total deformation (%)	Von Mises stress (%)	Shear stress (%)
<b>Starboard shell</b>	0.4	-0.58	-0.83	-0.56
	0.6	-0.61	-1.11	-0.62
<b>Frame 121</b>	0.4	-0.35	2.05	2.17
	0.6	-0.35	2.16	2.33

**Table 5.** The influence of the friction coefficient on FE analysis's output values resulting from the impact on the barge's structure with E= 1kJ (v=1m/s) at frame 123 (x= 65.62 m, y= 3.19 m, z= 5.44 m).

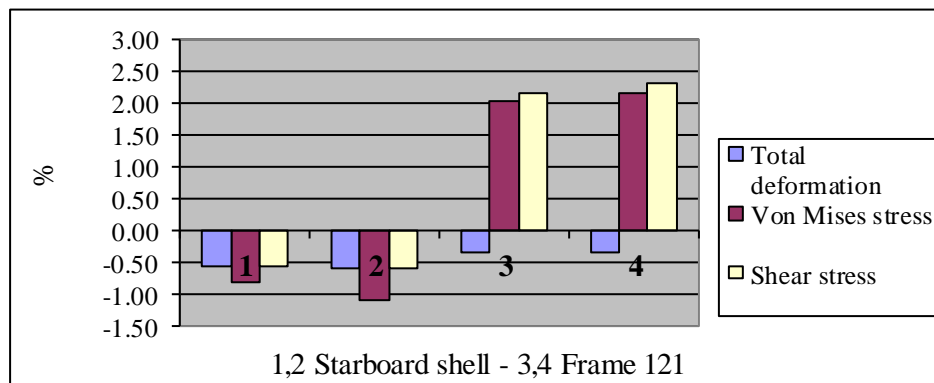
Structure elements	Friction coefficient $\mu$	Total deformation (%)	Von Mises stress (%)	Shear stress (%)
<b>Starboard shell</b>	0.4	-0.28	0.27	0.34
	0.6	-0.28	0.33	0.26
<b>Frame 123</b>	0.4	-0.17	-0.72	-0.16
	0.6	-0.17	-0.74	-0.21

The barge's structure behaviour under impact load, considering two values for friction coefficient, is presented, on percentage in table 4, table 5, table 6 and diagrams from figure 3, figure 4 and figure 5. The friction coefficient  $\mu = 0$  is considered, as reference, in all results for numerical barge's structural analysis.

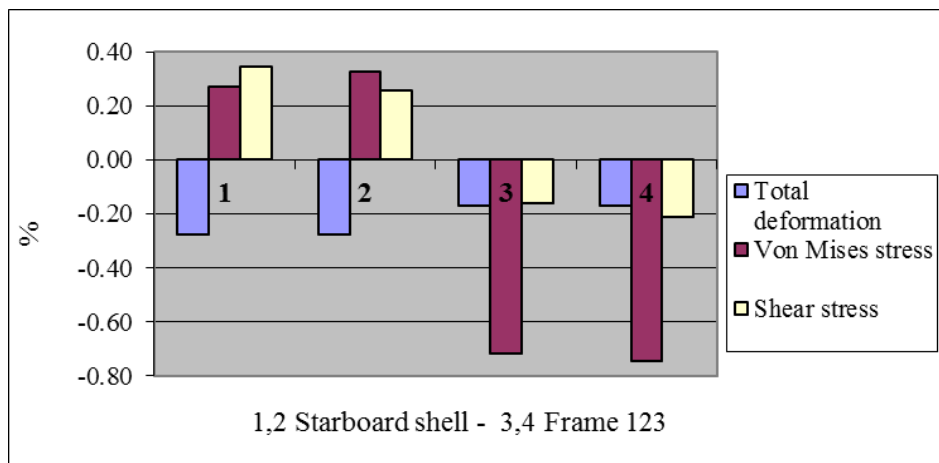
**Table 6.** The influence of the friction coefficient on FE analysis's output values resulting from the impact on the barge's structure with E= 1kJ (v=1m/s) at frame 125 (x= 66.62 m, y=3.19 m, z= 5.29 m).

Structure elements	Friction coefficient $\mu$	Total deformation (%)	Von Mises stress (%)	Shear stress (%)
<b>Starboard shell</b>	0.4	-2.39	-1.40	-2.04
	0.6	-2.39	-1.13	-2.32
<b>Frame 125</b>	0.4	-2.29	1.13	1.39
	0.6	-2.29	0.94	1.49

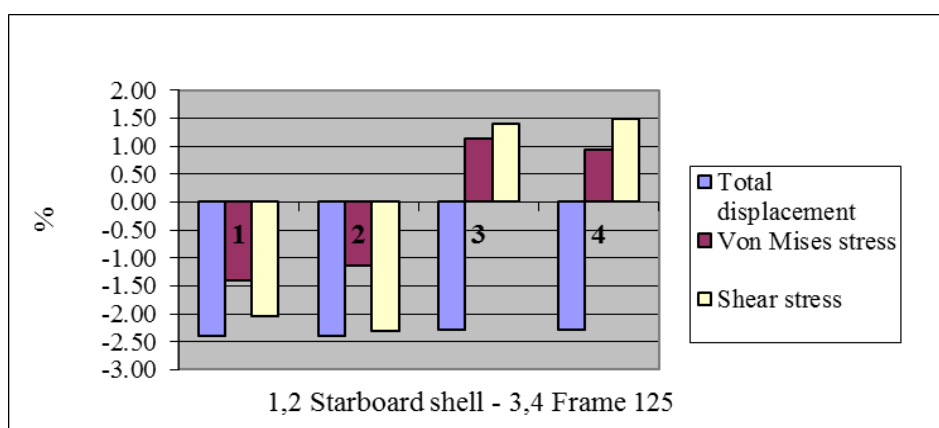
In these diagrams, on X axis, are presented the results corresponding to each friction coefficient, for starboard shell and frames. Values 1 and 3 are used as references for  $\mu = 0.4$ , and values 2 and 4 are mentioned to  $\mu = 0.6$ . The friction coefficient generates the decreasing of total deformation of the starboard shell and stiffeners nodes, as it can be observed in diagrams from figure 3, figure 4 and figure 5. The total deformations values are identical for both values of friction coefficients, except starboard shell values from table 4.



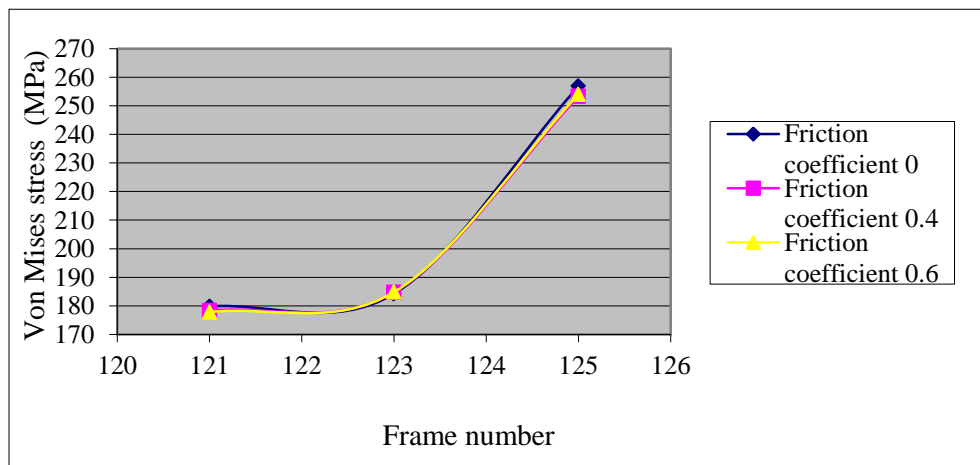
**Figure 3.** The diagram of the friction coefficient influence's on the output values resulting from the impact on the barge's structure with  $E=1$  kJ ( $v=1$  m/s) at frame 121 ( $x=64.62$  m,  $y=3.19$  m,  $z=5.49$  m).



**Figure 4.** The diagram of the friction coefficient's influence on the output values resulting from the impact on the barge's structure with  $E=1$  kJ ( $v=1$  m/s) at frame 123 ( $x=65.62$  m,  $y=3.19$  m,  $z=5.44$  m).



**Figure 5.** The diagram of the friction coefficient's influence on the output values resulting from the impact on the barge's structure with  $E=1$  kJ ( $v=1$  m/s) at frame 125 ( $x=66.62$  m,  $y=3.19$  m,  $z=5.29$  m).



**Figure 6.** The influence of barge's geometry on starboard shell's Von Mises stress under  $E = 1 \text{ kJ}$  ( $v = 1 \text{ m/s}$ ), at frames 121, 123 and 125.

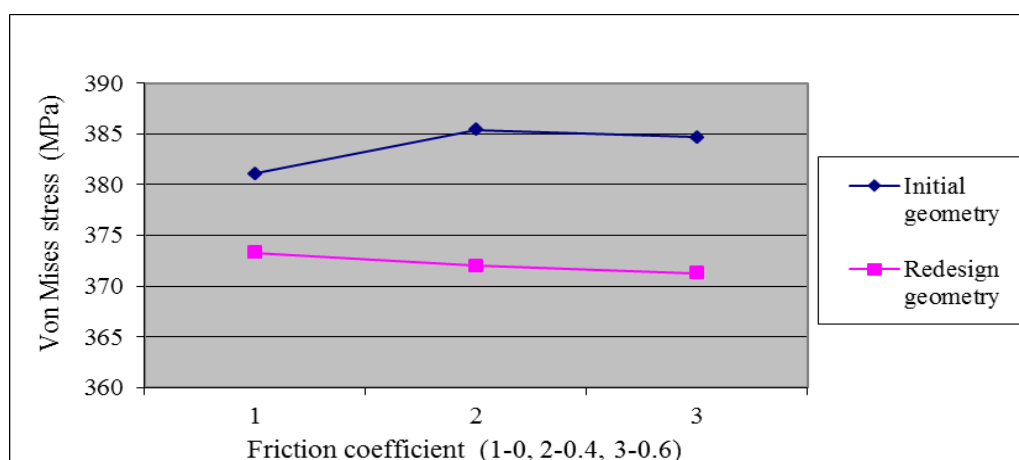
The influence of the barge's geometry on Von Mises stress under impact loads is presented in figure 6. It is observed that an increasing of Von Mises stress from 177.8 MPa, at frame 121 that have small curvature, to 254 MPa at frame 125, where the curvature is greater. The friction coefficient is  $\mu = 0.6$  and similar behaviour is observed also for  $\mu = 0.4$ .

### 3.2. Impact FE analysis on redesigned barge's structure

The increasing of thickness elements was chosen as a method to diminish the Von Mises stress during impact load. The starboard shell and frame 125 design dimensions are presented in table 7.

**Table 7.** Alternative data for redesigning the barge's geometry

Geometry	Starboard shell thickness (mm)	Frame 125 Thickness (mm)	Mass (tones)	Mass change (%)
Initial	6	6	4.644	-
I	6	7	4.651	0.151647
II	7	6	4.696	1.127029



**Figure 7.** A compared study of the friction coefficient influence on Von Mises stress for different barge's geometry at frame 125.

It was observed that increasing thickness to 7 mm for starboard shell table generate the diminishing of Von Mises stress, as presented in figure 7.

#### 4. Conclusions

The numeric analyses that consider impact loads on starboard shell in three points with different curvature, with  $E=1$  kJ ( $v=1$ m/s) show that the friction coefficient values determine the decreasing of total deformation values of starboard shell and frame's nodes.

The increase in starboard shell curvature (from frame 121 to frame 125) causes an increase in Von Mises stress with 42.85%, considering  $\mu = 0.6$ .

The increase in table thickness of starboard shell (from 6 mm to 7 mm) with 16.6 % causes a decrease in Von Mises stress with 3.47% at frame 125, compared to similar values of initial geometry. It also generates the increase in the structure mass with 1.12% that causes the Von Mises stress to decrease with 3.47 % at frame 125, compared to similar values of initial geometry.

It is observed that barge's structure curvature influences the Von Mises stress values and our future paper will deal on influence of different geometries on strain values under impact load.

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